A ROAD TEST COMPARISON OF REACTION TIMES USING AN OPERATIONAL COMBINED BRAKE-ACCELERATOR PEDAL AND THE CONVENTIONAL BRAKE PEDAL

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THESIS

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ABSTRACT

This experiment was conducted to compare road test reaction times obtained from a dual-function pedal that was completely integrated into an automobile's accelerating and braking systems.

The resultant mean reaction times, measured from seventeen subjects in tests at Laguna Seca Raceway, Monterey, California, were 0.316 seconds for the dual-function pedal and 0.450 seconds for the conventional brake pedal. Analysis of variance showed that the reaction time when using the dual-function pedal was significantly faster than reaction time when using the conventional pedal at the p = .01 level. The results of this experiment show that reaction times using the combined brake-accelerator pedal are faster by 29.8% (corresponding to reducing the stopping distance by 12 feet at 60 miles per hour), than those using the conventional system.

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Lastly, the authors express their appreciation to those who were inconvenienced by volunteering their time and efforts to participate in good spirits as test subjects.

I. INTRODUCTION

Much has been written on the automobile and its impact on the societies of the United States and other developed nations of the world. Its impact has been felt in innumerable areas; just a few being the standard of living, population shifts and environment. Gruesome figures reflect the automobile's death and injury-dealing impact on the population. Such accident statistics are well known to the contemporary reader and need not be repeated here.

In addition to causing death and injury, every automobile owner has felt the bite of automobile accidents in his pocketbook, whether or not he personally has been involved. The prices of automobiles continually rise as a result of installation of mandatory safety equipment. The cost of insurance rises to cover dollar losses of the policy issuing companies. Much of this because labor and material costs for repairing minor "fender-benders" have risen sharply with inflationary pressure. There is Congressional "shouting" for the automobile industry to provide a truly protective bumper, an indication of national interest in reducing such high repair costs.

Most accident situations develop in seconds or fractions of seconds during which the driver must sense the danger, decide to act to avoid the danger and carry through his decision by operating the controls of his automobile.

Each of these discrete actions use time available to avoid the accident. It appears the greatest research in the automobile industry targets protection of the occupants of an automobile once it becomes involved in an accident. Virtually all companies, domestic and foreign, have developed a prototype safety vehicle. Devices incorporated into these vehicles include elaborate shock-absorbing restraining belt systems, heavy interior padding, collapsing steering columns, automatically inflating air bags, radar or electrical accident sensing alarms, and more. There appears, however, to be a lack of research into providing the driver a greater margin of error by providing him more time to stop or maneuver.

Traffic snarls within population centers at peak hours have caused the development of rapid transit systems in urban areas to become a national rather than local issue. Such congestion on the roads suggests focusing on one of the most frequent type accidents, the rear end collision, and determining the effect of drivers' reaction time in emergency situations. An interesting car-following model was prepared by E. A. Brill [1971]. Quoting from Brill:

> "...Somewhat surprisingly the conditional probability of a car being involved in an accident, given no previous accident, is shown to be a function of the cumulative effects of the reaction times and temporal headways of those cars preceding it in the traffic jam...It is shown that the change in 'collision' probability corresponding

to an additive shift in expected reaction time is in fact multiplicative. Thus, a shift upward in expected reaction time could explain higher accident rates in inclement weather, while a downward shift could predict the accident saving benefits of a man-machine braking system with lower reaction time..."

Thus, this problem of getting the braking system applied quicker, the reaction time problem, should be the target for action.

The reader has likely experienced various relative placements of accelerator and brake pedals. In many cases the brake pedal appears to have been positioned without such design considerations as the distance and direction the right foot must travel to reach the brake from the accelerator. These are clearly major variables influencing the time required to react in an emergency. Most exhasperating perhaps is the brake pedal found located high above the accelerator position such that the right foot catches on the side of the brake pedal in a rush to apply the brakes, thereby causing the loss of possible life-saving fractions of time. Not all designs appear poorly arrived at. Some in fact appear well thought out and require only that the right toe be moved left to the brake, pivoting off the right heel, removing any need to physically lift the right foot or leg. Of course, when determining these relative pedal placements,

the positioning must also take into account various foot sizes. The pedals cannot be so close that they interfere with free movement.

This paper deals with reducing driver reaction time by eliminating the relative placement problem and reducing to zero the movement distance which the foot must travel from accelerator to brake. This can be accomplished by installing a dual-function pedal, the combined accelerator-brake pedal. The accelerator is operated by depressing the toe as in a conventional two pedal system, but depressing the heel, with or without removing the pressure of the toe, automatically disengages the accelerator linkage and applies the brakes.

II. BACKGROUND

A. LITERATURE

The first experiments with a dual-function pedal which revealed a significant reduction in reaction time when compared with separate pedals were begun in 1967 at Kansas State University [Chawla 1969] with a dual fulcrum pedal. The results of the first experiments with a single fulcrum dual-function pedal conducted at the Naval Postgraduate School were released in October 1969 [West 1969]. Subsequent test results were released in April 1970 [Toben], September 1970 [Sullivan], and in September 1971 [Costain]. A summary of these tests and their results is shown in Tables 1a and 1b.

B. DEFINITIONS

1. The following definition applies to this experiment and past experiments.

a. Reaction Time

Reaction time is the sum of movement time and non-movement time.

(1) Non-movement time: the time required for the individual to sense an alerting signal and decide to apply the brake system.

(2) Movement time: having decided to apply the brake system, the time required to physically begin application of the brake system by depressing the appropriate brake pedal.

TABLE 1a.

Experimenter	Summary of Investigation	Results
West, A.E.	Compared pedal of the hinged design with a pedal of one piece design in a laboratory environment.	Pedal of one piece design proved to be the fastest integrated design
Toben, T.J.	Used pedal of one piece design from West's experiment and compared reaction times as a function of floor angle and rotational angle in a laboratory environment.	Floor angle of 55° and rotational angle of 0° resulted in fastest mean reaction time and was significantly faster than all floor/rotational angle combinations except for $55^{\circ}/15^{\circ}$
Sullivan, J.P.T.	Compared the new dual-function pedal with a conventional braking system, (AAA testing device), and introduced a new variable, seat tilt. Laboratory environment.	Seat tilt did not affect reaction time. The new pedal resulted in significantly faster reaction time.
Costain, P.A.	Compared reaction times of the new dual-function pedal with a conventional braking system in an operational road test. Variables of speed and road condition were introduced.	Road conditions and speed did not affect mean reaction times. The new dual-function pedal resulted in significantly faster reaction times.

TABLE 1b.

Experimenter	Treatment	Mean Reaction Time
West, A. E. (1969)	Hinged-design pedal	0.235 sec
	One piece pedal	0.224
Toben, T. J. (1970)	$55^{o}/0^{o}$*	0.286
	$55^{o}/15^{o}$	0.295
Sullivan, J. P. (1970)	AAA testing device (two pedals)	0.468
	Dual-function pedal	0.259
Costain, P. A. (1971)	Conventional system (two pedals)	0.470
	Dual-function pedal	0.302

*Floor angle/Rotational angle

2. The following new definitions apply to this experiment (see figure 1).

a. <u>Pedal Travel (PT)</u>

The distance traveled by the shaft attached to the heel section of the dual function pedal when applying the brakes.

b. <u>Lower Linkage Travel (LLT)</u>

The distance traveled by the horizontally mounted transfer rod of the brake pedal which transfers movement to the linkage arm when depressing the pedal.

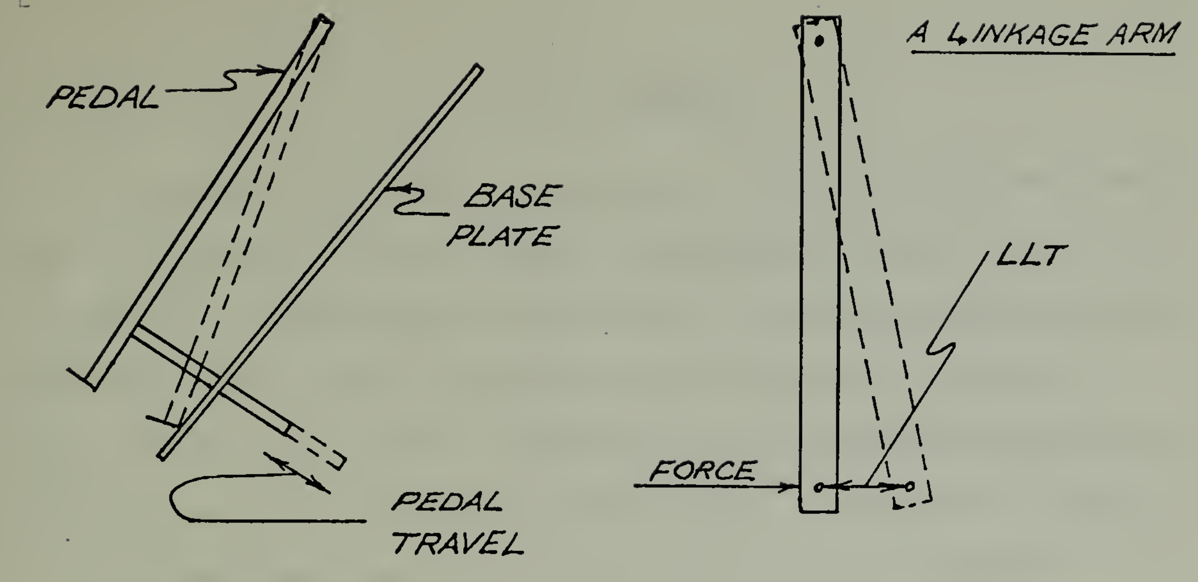
c. <u>Upper Linkage Travel (ULT)</u>

The distance traveled by the linkage arm at the point at which a piston from the master cylinder is attached when depressing the pedal.

d. <u>Mechanical Advantage (MA)</u>

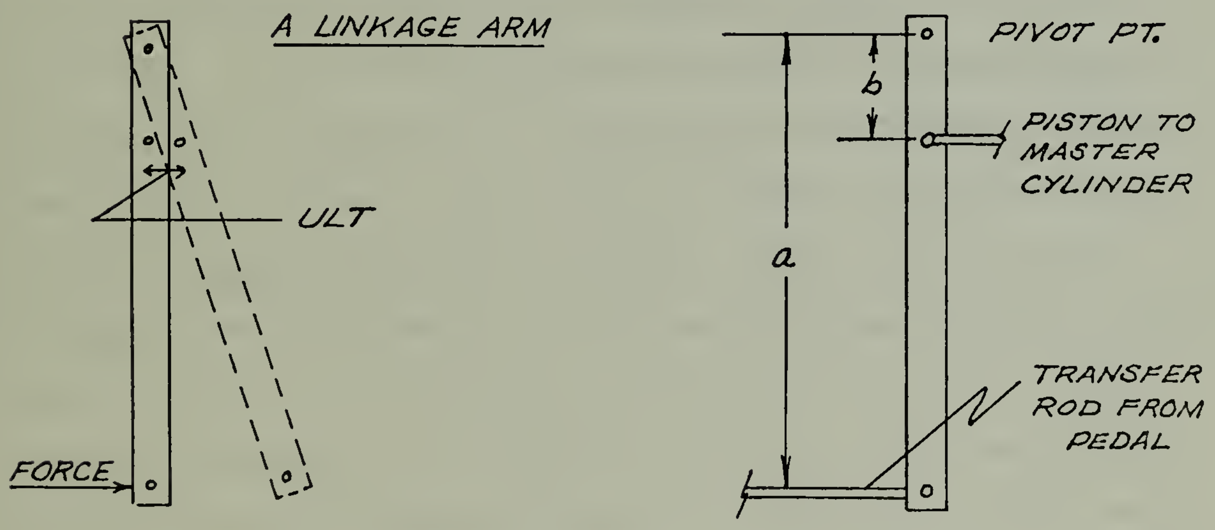
The ratio of (a) the distance from the fixed pivot point of the linkage arm to the point at which pedal pressure is applied, to (b) the distance from the fixed pivot point of the linkage arm to the point where the master cylinder piston rod is attached.

$$MA = (a)/(b)$$



a. Pedal Travel

b. Lower Linkage Travel (LLT)



c. Upper Linkage Travel (ULT)

d. Mechanical Advantage = a/b

figure 1. Definitive examples.

III. PROBLEM

As pointed out by P. A. Costain [1971], the three tests prior to his own at the Naval Postgraduate School were conducted in a laboratory environment. He recognized the need to evaluate the dual-function pedal reaction times with those of a conventional two pedal system under actual road conditions in an operating automobile. Through his labors a 1964 Dodge was modified to accept the one piece dual-function pedal used in previous experiments in the laboratory. The accelerator linkage was connected to the new pedal and the pedal was installed where the old accelerator pedal had been located. Microswitches were positioned so as to enable the recording of reaction times of the two systems. It is to be emphasized here that his experiment evaluated the effects of a real driving environment, speeds and road conditions, but it did not compare reaction times of two <u>functioning</u> braking systems. That is, the conventional braking system was intact and provided braking action when the pedal was depressed, but the dual-function pedal was not connected to a hydraulic braking system and braking action was only simulated when the dual-function pedal was depressed. The problem addressed in this study was therefore threefold.

<u>First</u>: To install the dual-function pedal in an automobile so that it was fully operational, i.e., worked as an accelerating and braking device.

Second: Under actual operational conditions, compare reaction times of an operational conventional system with those achieved with a dual-function system.

Third: To compare the results with the results of previous experiments.

IV. THE EXPERIMENT

A. PURPOSE

This experiment was designed to obtain brake reaction time data for two different operational braking systems at two moderate speed categories, 20-30 miles per hour and 30-40 miles per hour, and five road conditions, downhill, curve left, uphill, curve right, and straightaway.

B. THE APPARATUS

The test vehicle used was a 1964 Navy Sedan (Dodge), the same vehicle used by P. A. Costain in his experiment. All modifications of the vehicle cited by Costain remained on the vehicle. Additional modifications were required to make the dual-function pedal fully operational. First, (figure 2) a second master cylinder and mounting plate were obtained. The mounting plate was modified so that it would fit flush against the fire wall of the engine compartment in a position to the lower left of the steering column. The piston rod was shortened so that it would mate with the linkage arm from the new pedal. Second, (figure 3) a hydraulic line was installed from the second (new) master cylinder to the existing hydraulic line at a point approximately four inches in front of the first (existing) master cylinder. Shut off valves were installed between each master cylinder and the brake lines leading to all four wheels. By opening one valve and closing the other a

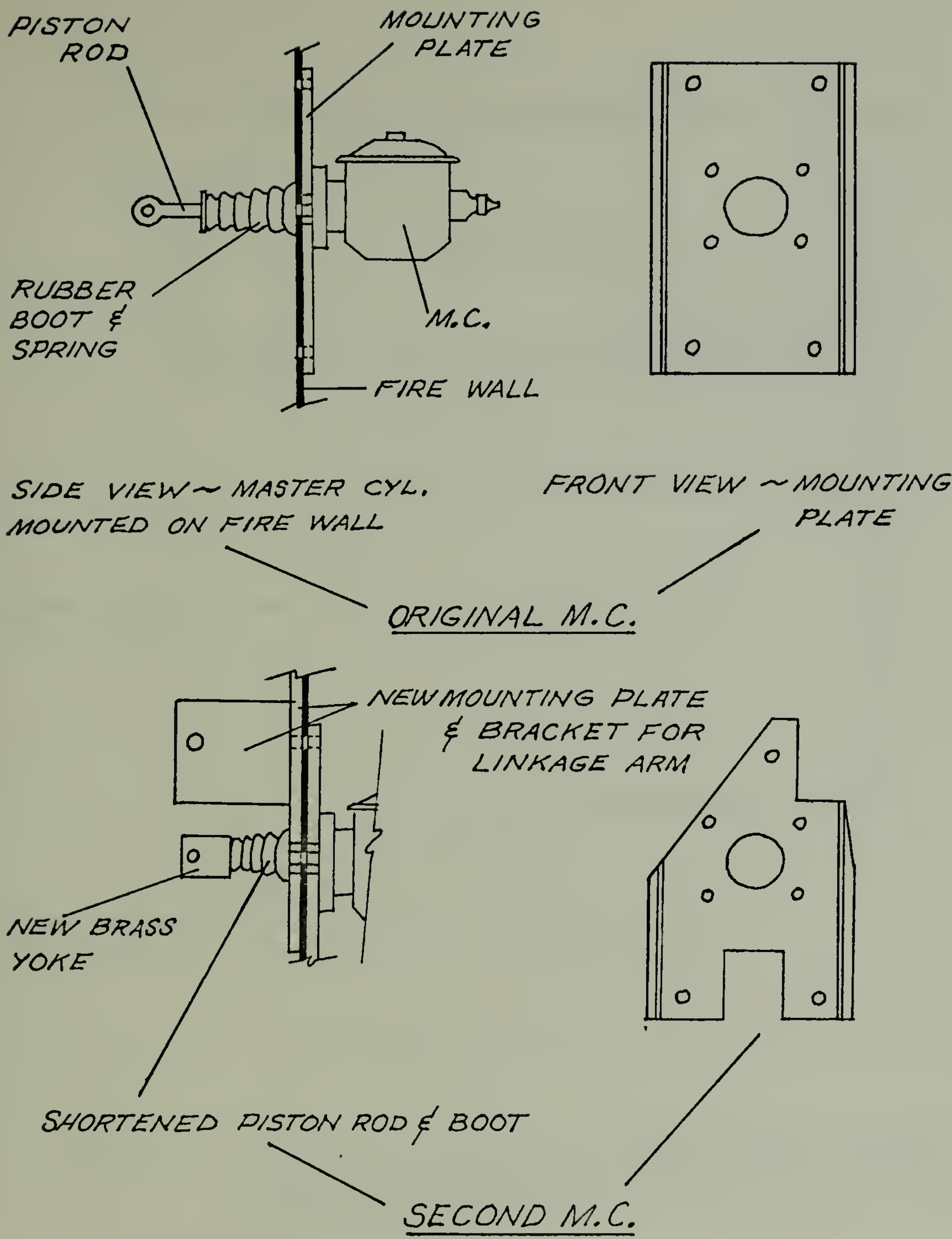


figure 2. Modifications to master cylinder required for installation of second system.

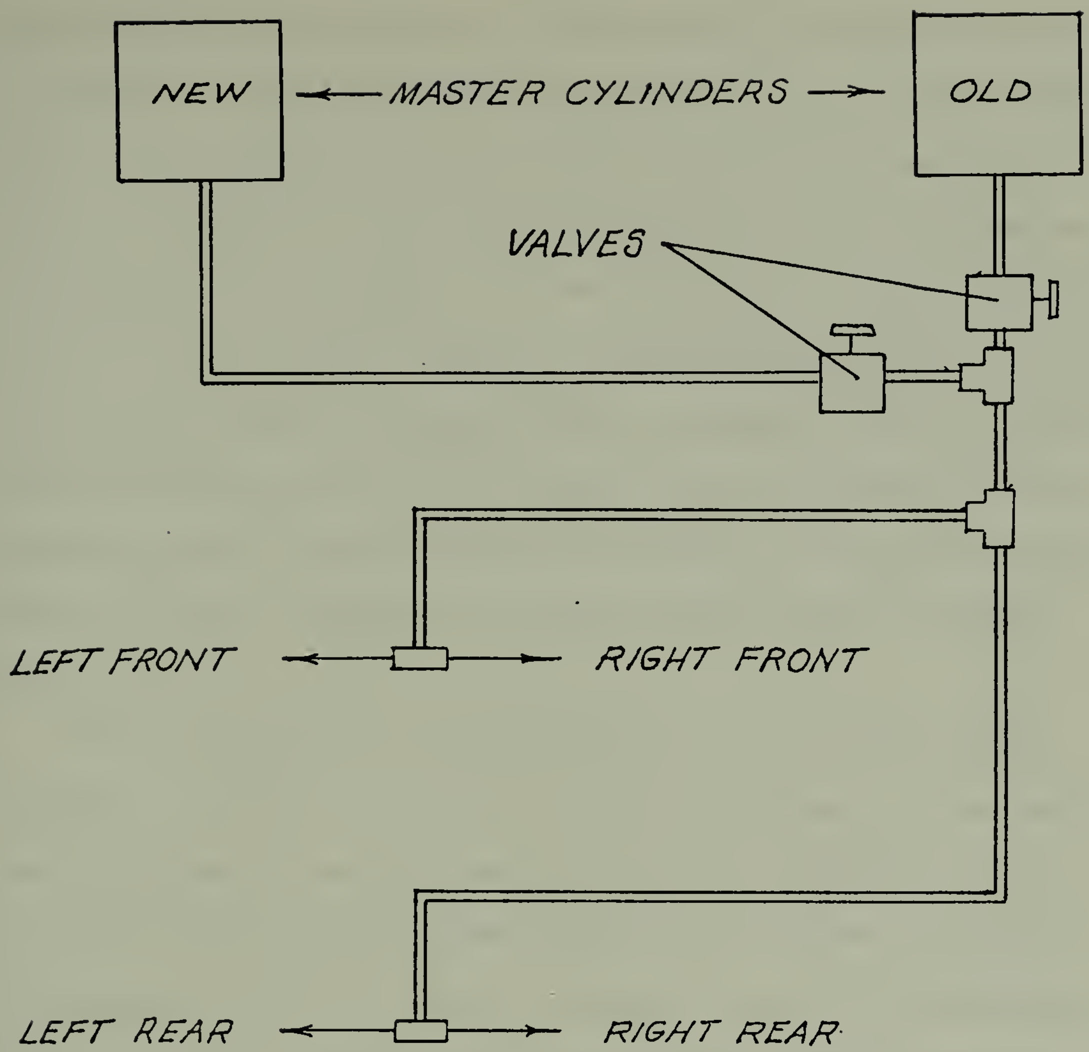


figure 3. Diagram of hydraulic system used to achieve braking action with conventional pedal or dual-function pedal.

particular braking system, conventional or dual-function, was selected and the master cylinder in the non-selected system was protected from backward hydraulic pressure. Third, (figure 4) a linkage arm was designed, fabricated and installed on the inside of the fire wall. A 1x1.5 inch hole was cut in the fire wall permitting the lower half of the arm to extend through to the outside of the fire wall. Physical limitations in the test vehicle constrained the design of the linkage arm to achieving a mechanical advantage of 5.9:1 whereas the conventional system provided 7:1.

The one piece dual-function pedal as modified and tested by Costain was used in this experiment. The pedal was modified in several ways so that it would be able to actuate the braking system (figure 5). First, the pedal was raised from the mounting plate to permit ample pedal travel for the upper and lower linkage travel needed to actuate the master cylinder. Second, the horizontally mounted transfer rod was threaded to accept a ball-bearing connector located between it and the lower linkage arm. Third, a tension rod was connected from the lower left corner of the mounting plate to the under frame of the vehicle to provide greater rigidity of the pedal housing when pedal pressure was applied. Final installation can be seen in figures 6, 7 and 8.

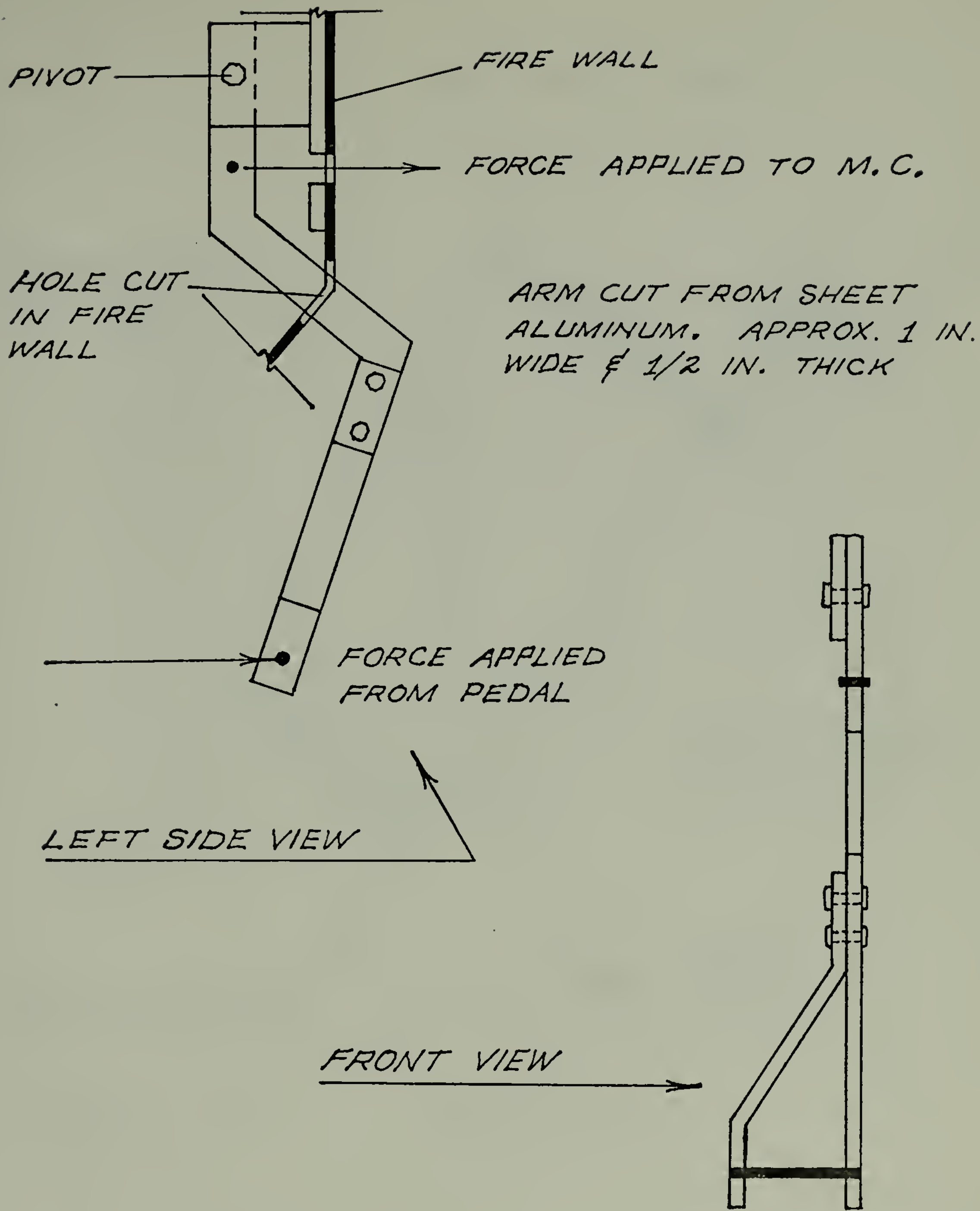


figure 4. Linkage arm used to activate master cylinder from dual-function pedal.

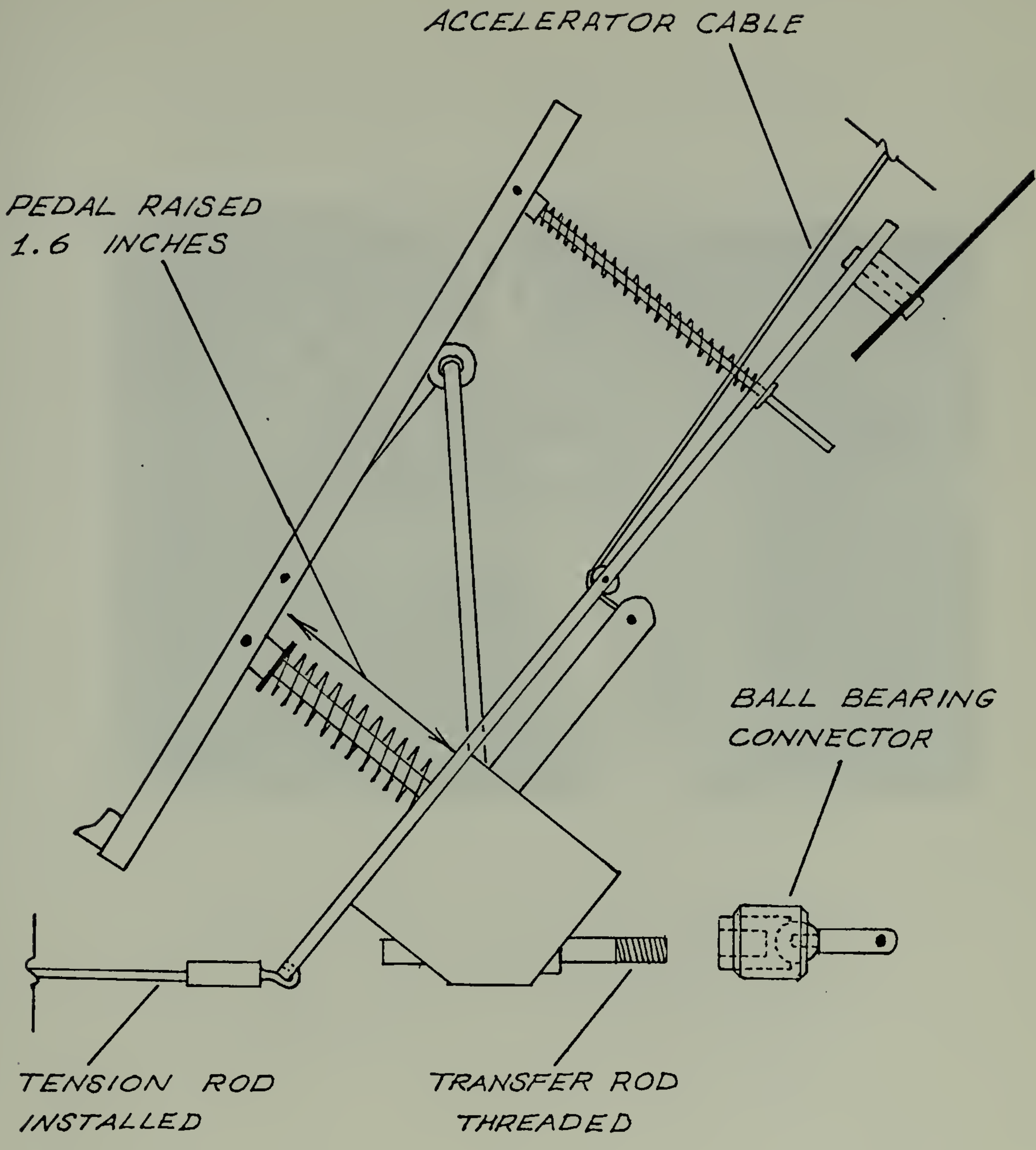


figure 5. The dual-function pedal, (not to scale), with modifications indicated.

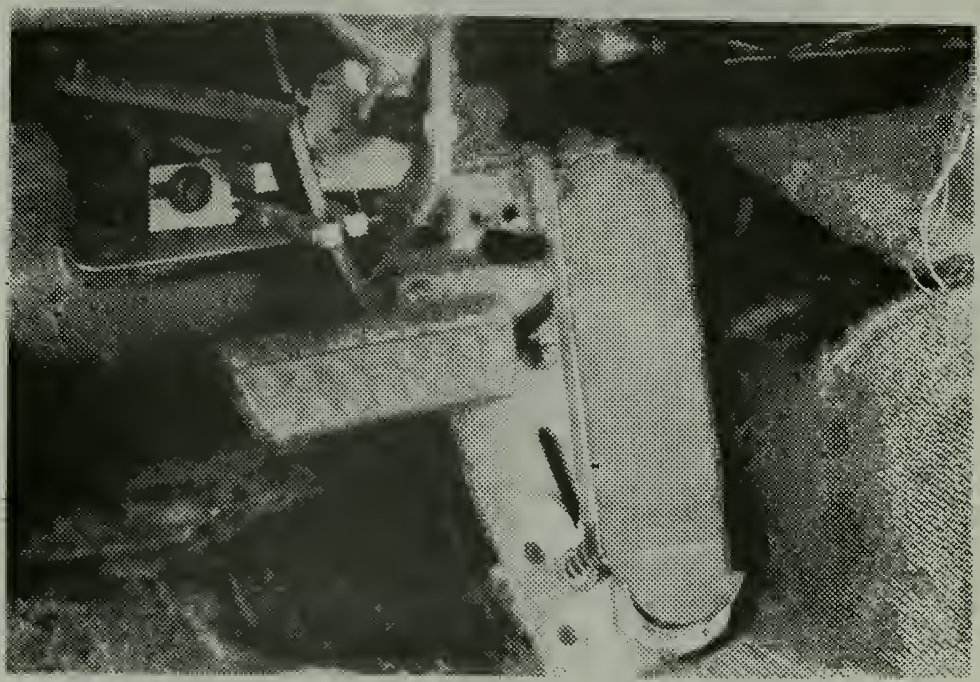


figure 6. Conventional brake pedal and dual-function pedal installed.

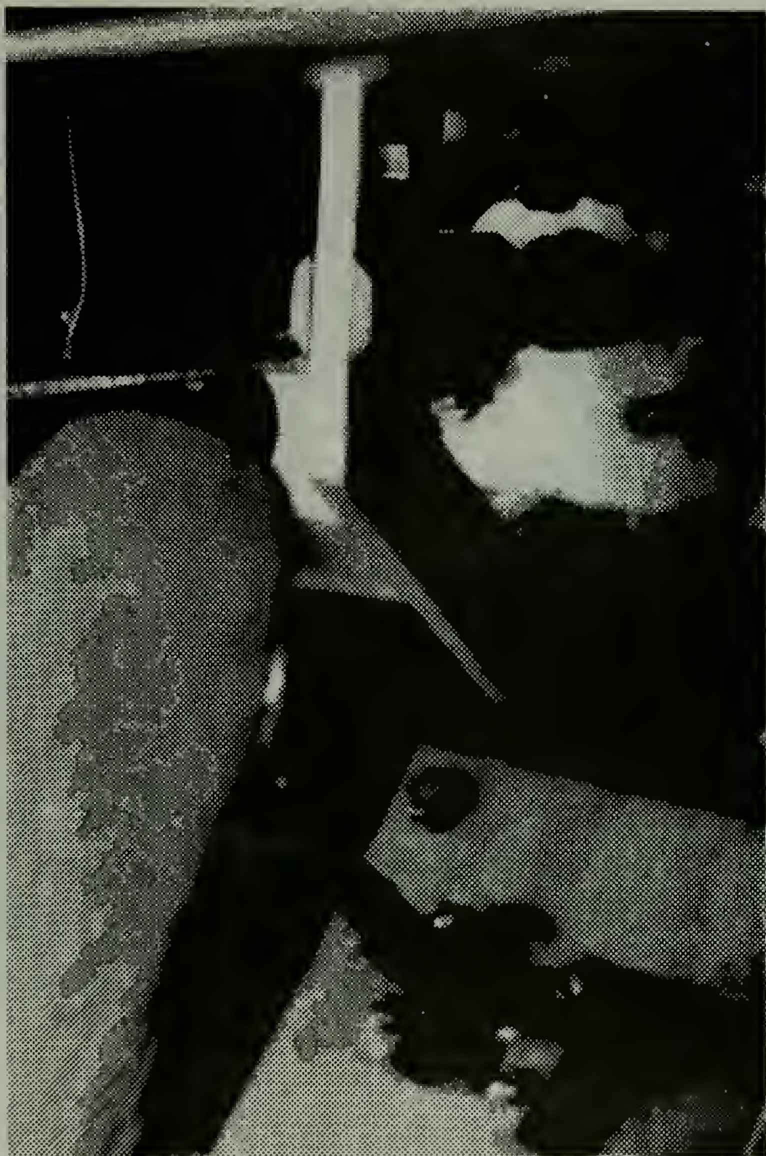


figure 7. Dual-function pedal and linkage arm.

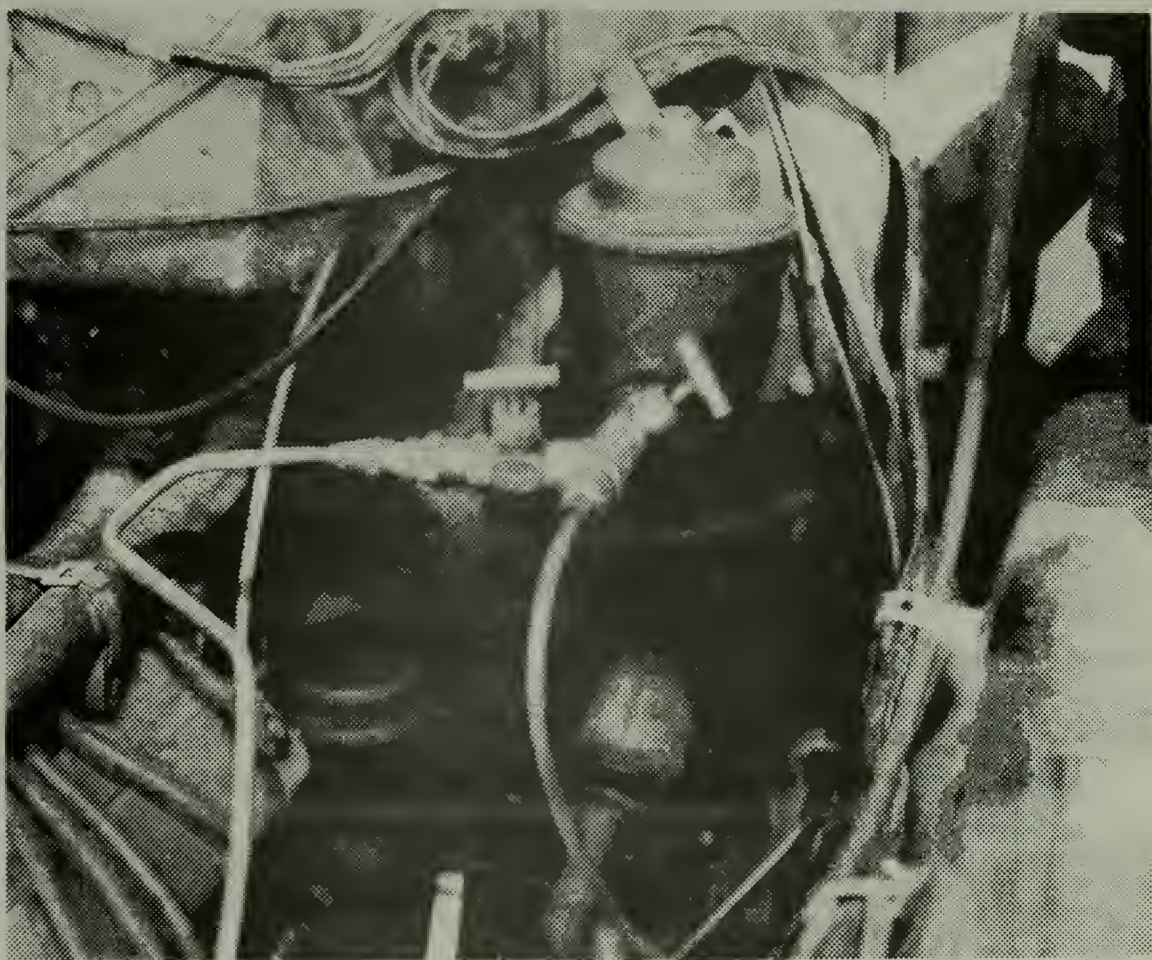


figure 8. Master cylinders and connecting lines.

The test equipment consisted of a sine wave counter-timer, a 12/110 volt inverter, a 2900Hz audible signal device, two microswitches, and a relay box. The simplified schematic shown in figure 9 depicts the connections used for the test.

The audible signal device was located in the center of the dashboard in the position normally occupied by the car radio. The signal was activated by a silent pushbutton switch controlled by the experimenter. A microswitch was mounted on each brake pedal system such that each was activated by 1/8 inch of pedal travel. The switches were connected in series and were normally in the closed position. Upon hearing the audible signal the subject was to apply the brakes through the use of the appropriate pedal, thereby opening the microswitch, breaking the circuit, and stopping the signal and the timing device.

The microswitch used with the conventional brake pedal was mounted as described by Costain (figure 10). The mounting of the microswitch used by Costain with the dual-function pedal interfered with movement of the horizontal transfer rod and had to be changed. The switch was remounted on the underside of the base plate, (figure 11).

C. ENVIRONMENT

The experiment was conducted at the 1.9 mile long Laguna Seca Raceway, Ft. Ord, California. The layout of

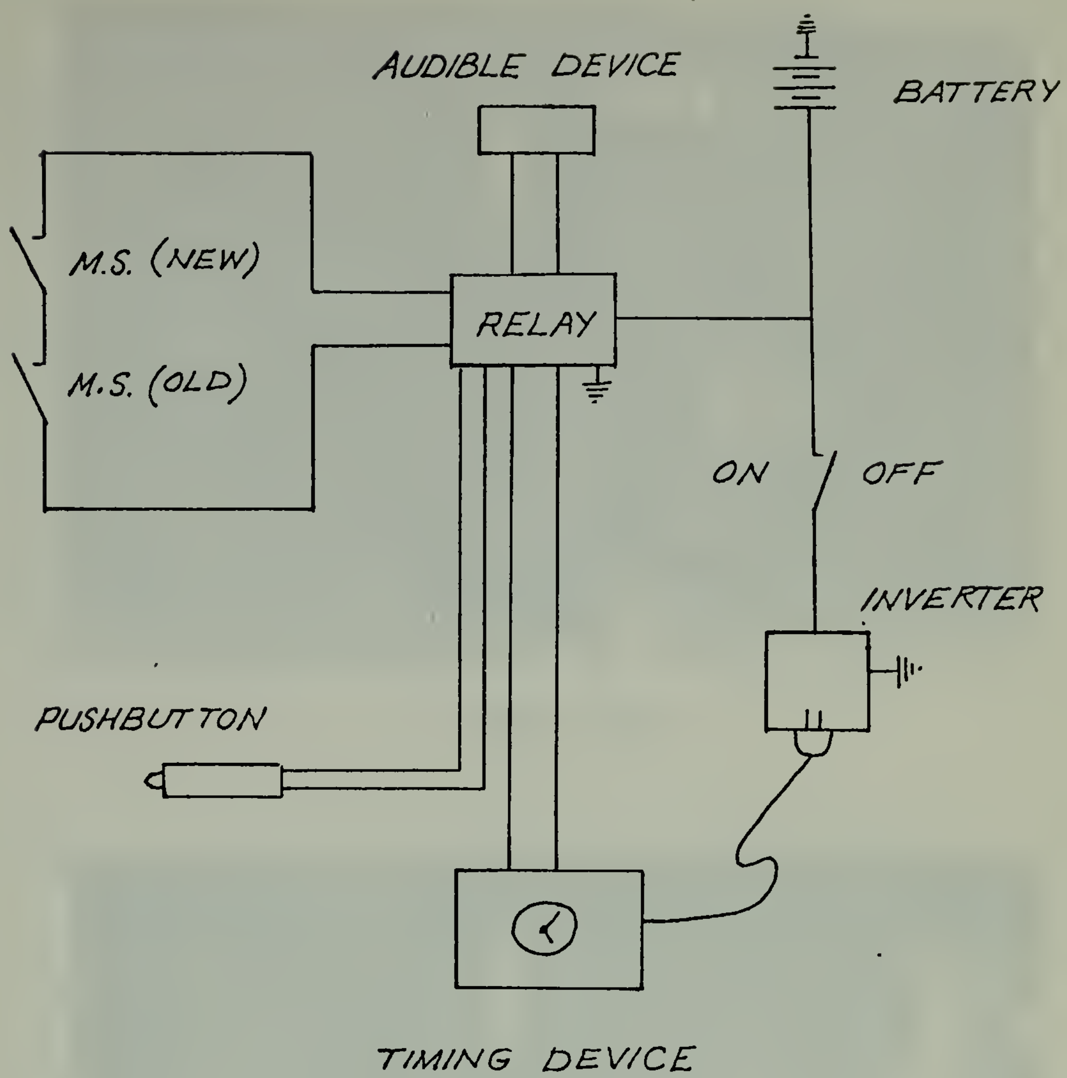
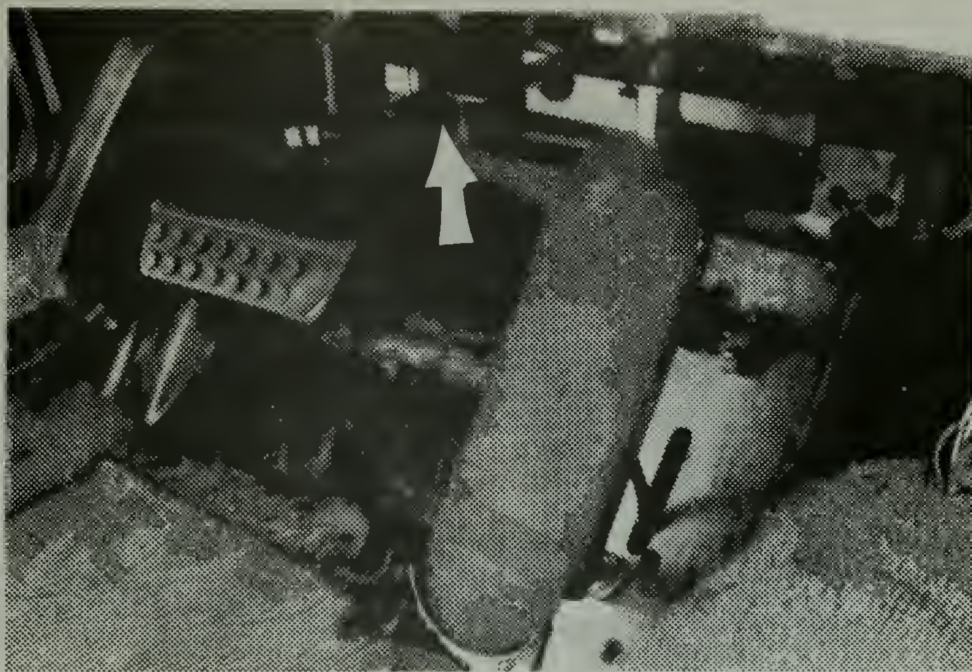
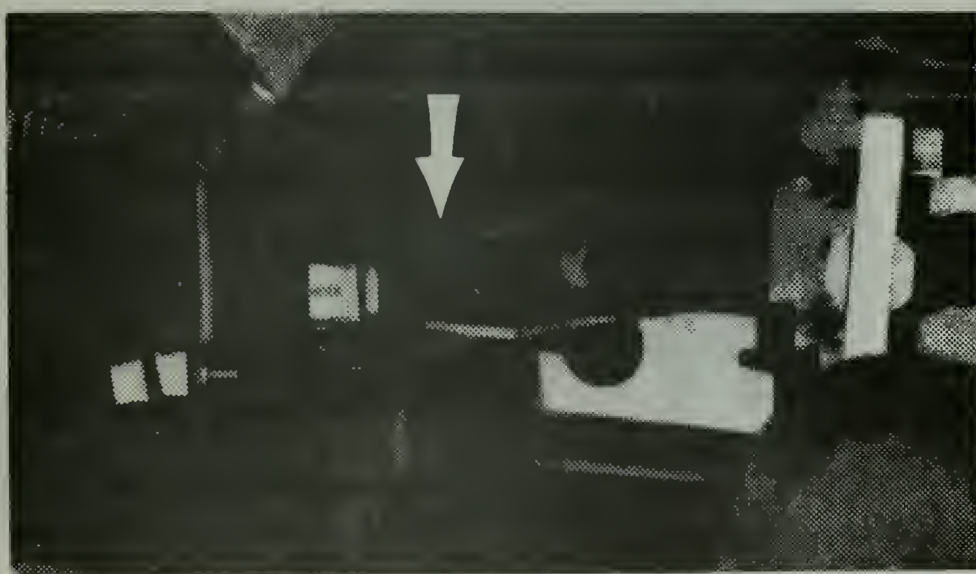


figure 9. Circuitry used with test equipment.

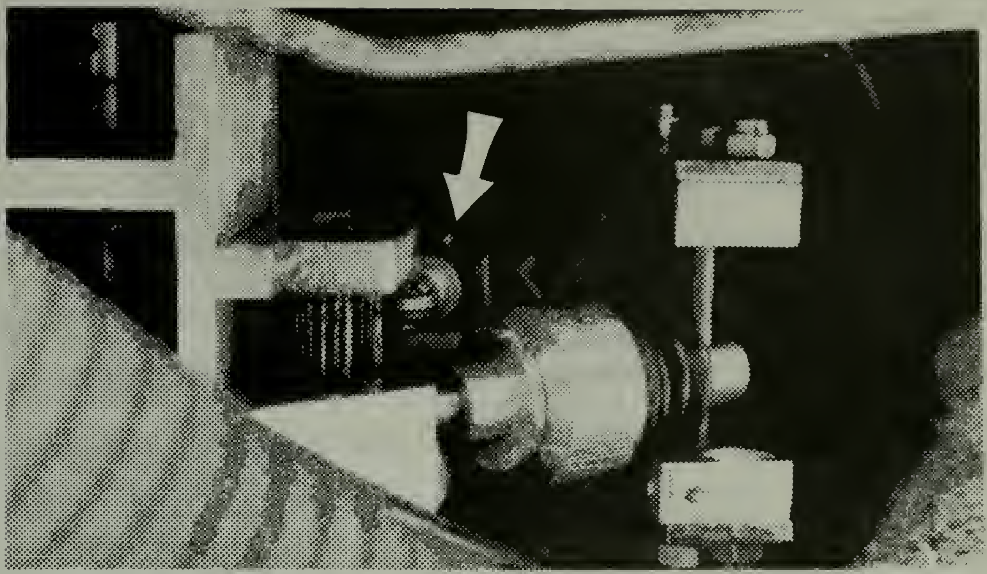


NORMAL VIEW



CLOSE VIEW

figure 10. Microswitch (conventional pedal)



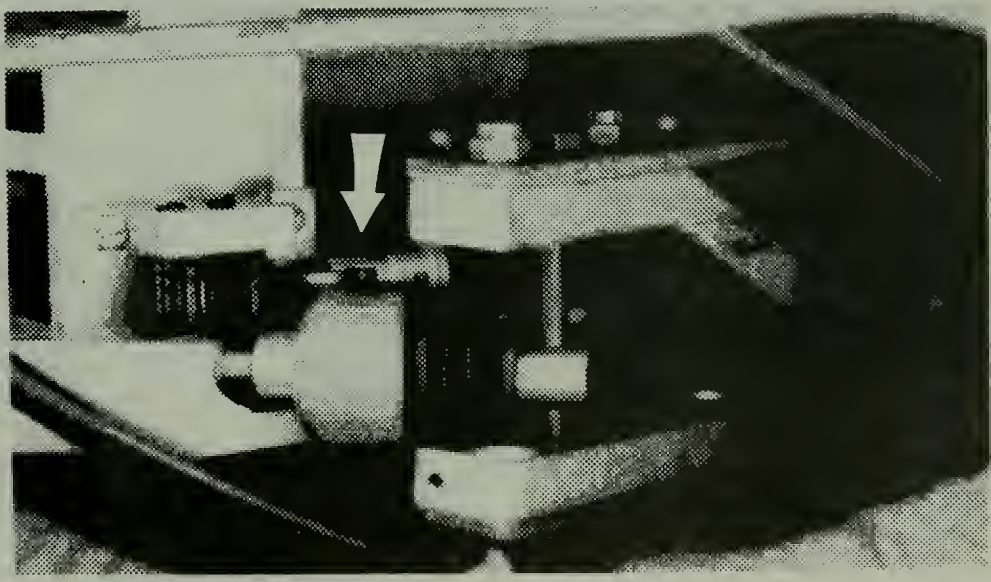


figure 11. Two views of microswitch (dual-function pedal).

the track presented ample opportunities to test the two pedals under the five road conditions previously specified. With the exception of some minor track maintenance activity, which in no way hampered the experiment, there was no other activity on the track during the five afternoons on which tests were conducted. All tests were conducted between noon and six o'clock under excellent weather conditions. Testing each subject required approximately 45 minutes.

D. SUBJECTS

Seventeen male students from the Naval Postgraduate School volunteered to be subjects in this experiment. The ages of the subjects, all officers on active duty with the Army, Navy, Marine Corps, or Coast Guard, ranged from 22 to 36 years. The average age of the subjects was 28.4 years. Fourteen subjects had 10 or more years of driving experience with conventional two and/or three pedal systems. The three youngest officers had 6, 8, and 9 years driving experience. Although several of the subjects had some knowledge of the combined pedal concept, none had participated in previous experiments with the pedal.

E. PROCEDURE

Prior to beginning the test each subject was given a form to read which outlined the purpose of the experiment, the equipment to be used and the procedure to be followed. Each subject was also briefed verbally before the test.

Upon completion of the briefing, the subject adjusted the seat, strapped himself in, put on a safety helmet and began one of two practice laps. One lap was completed with each brake system (conventional pedal or dual-function pedal). These two practice laps were to allow the drivers to become familiar with the pedals to be tested, the track, the characteristics of the test vehicle, the speeds to be maintained, and the test signal. During the practice laps the subjects were told their reaction time after each signal as a motivation for achieving fastest possible reaction times on both systems. The subjects were told that they were liable for a signal anywhere on the track except for a steep, downhill S-turn on the back side of the track where their total concentration was required to keep the car on the track.

After the two practice laps (approximately 4 miles of driving) the subjects began the test. Eight complete laps of the track were made by each subject with the following test configurations:

Two laps at 20-30 mph with conventional pedal

Two laps at 20-30 mph with combination pedal

Two laps at 30-40 mph with conventional pedal

Two laps at 30-40 mph with combination pedal

The sequence of these laps was randomly assigned for each subject. The two ranges of speeds, 20-30 miles per hour and 30-40 miles per hour, were chosen rather than specific

speeds such as 25 and 35 miles per hour because it was found to be nearly impossible to maintain an exact speed due to the nature of the track and the random braking during the test. During each lap each subject was tested on each road condition, downhill, curve left, uphill, curve right and straightaway. On each lap ten signals were given, five of which corresponded to preselected locations for each of the five road conditions and five given at random locations. The subjects were told to regard each signal as an indication of an emergency situation and to brake accordingly (i.e., as fast as possible).

The design of the test provided 40 data points per test subject, representing two recordings at each road and speed configuration for each pedal system (see sample data sheet, figure 12).

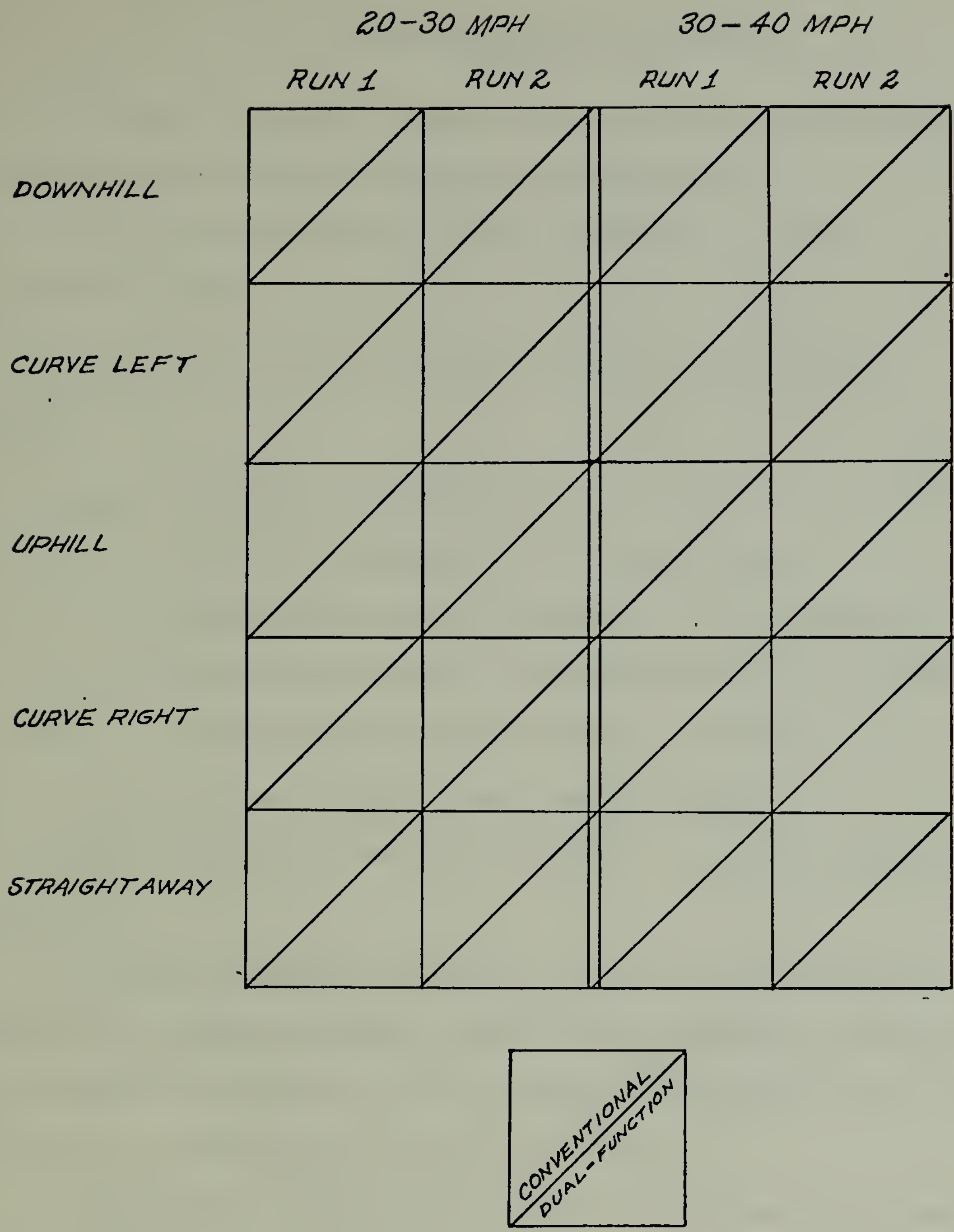


figure 12. Sample data sheet used for data collection (one data sheet per test subject).

V. DATA ANALYSIS AND RESULTS

The mean reaction time for each treatment combination used in the experiment is shown in Table 2.

The linear statistical model assumed for this experiment was:

$$T_{ijkl}=\mu+P_i+C_j+S_k+PC_{ij}+PS_{ik}+CS_{jk}+PCS_{ijk}+e_{l(ijk)}$$

where

T_{ijkl} is brake reaction time

μ is the true mean for all observations

P_i is the effect due to pedal type (2 levels)

C_j is the effect due to road conditions (5 levels)

S_k is the effect due to speeds (2 levels)

$e_{l(ijk)}$ is the random experimental error

PC_{ij}, PS_{ik}, CS_{jk}, PCS_{ijk} represent interactions between factors.

The null hypothesis was that there is no difference among the effects of pedal type, road condition and speed on brake reaction time. The alternate hypothesis was that there is a difference among the effects.

A three way, fixed effects analysis of variance was the approach used to test the above hypothesis. As indicated in Table 3, the Three Way Anova showed that at p=0.01 the only significant difference was in the pedal type. This result agrees with Costain's findings.

TABLE 2

Mean Reaction Times
(seconds)

Road Condition	20-30 MPH		30-40 MPH	
	Combined Pedal	Conventional Pedal	Combined Pedal	Conventional Pedal
Downhill	0.312	0.456	0.320	0.446
Curve Left	0.318	0.437	0.335	0.428
Uphill	0.317	0.448	0.310	0.436
Curve Right	0.313	0.442	0.313	0.467
Straightaway	0.313	0.460	0.304	0.475

TABLE 3

Three Way ANOVA

Treatment	df	Mean Square	F Value	*p*
Pedal Type (P)	1	3.0600	540.18	.01
Road Condition (C)	4	0.0021	0.38	NS*
Speed (S)	1	0.0029	0.52	NS
P x C	4	0.0130	2.29	NS
P x S	1	0.0005	0.08	NS
C x S	4	0.0022	0.40	NS
P x C x S	4	0.0028	0.48	NS
Error	660	0.0056		
Total	679	3.0791		

*Not Significant = NS

In order to compare the mean reaction times obtained by Costain with the data collected in this experiment, a test of the two population means was conducted. Here the hypothesis was that the two populations have the same mean when is not known. The test statistic used was:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\left[S_p^2 \left(\frac{1}{N_1} + \frac{1}{N_2} \right) \right]^{1/2}}$$

where S_p^2 is the pooled mean square estimate of given by:

$$S_p^2 = \frac{(N_1 - 1) S_1^2 + (N_2 - 1) S_2^2}{N_1 + N_2 - 2}$$

Table 4 shows that the hypothesis is accepted at the $\alpha = 0.01$ level. This means that the mean reaction time of this test and the mean reaction time found by Costain [1971], are not significantly different and that a 99% confidence is given to this statement.

TABLE 4

Student's t-test for Difference Between Mean Reaction Times of this Experiment and that of Costain

Conventional Brake Pedal

Experiment	Sample Size	Sample Variance	Sample Mean
Road Test (1)[a]	13	0.002025	0.470
Road Test (2)[b]	17	0.002624	0.450

Pooled Variance = 0.002367
t = 0.409

Combined Brake Pedal

Experiment	Sample Size	Sample Variance	Sample Mean
Road Test (1)[a]	13	0.001156	0.302
Road Test (2)[b]	17	0.001537	0.316

Pooled Variance = 0.001374
t = 0.998

(a) Costain [1971].
(b) Most recent experiment

VI. DISCUSSION AND CONCLUSION

The results of this experiment agree with previous investigations of the combined brake-accelerator concept Costain, [1971]. Road conditions and speed variations did not significantly affect brake reaction time; however, reaction time with the combined pedal was significantly faster than with the conventional system (29.8% faster in this experiment which implies approximately 12 feet shorter stopping distance when traveling at 60 miles per hour).

The major purpose of this experiment was to test a fully functional combined pedal under normal driving conditions. The lack of a significant difference between the results of this experiment and the road tests conducted by Costain lend further credibility to the theory that a viable dual-function pedal can be developed that will add further safety to the highways.

It may be noted that the average reaction time for the dual pedal in this experiment was slightly higher than the average as found by Costain. This may be due to the fact that the subject, when depressing the pedal, was actually engaging the braking system, whereas, in Costain's experiment, depression of the pedal met no resistance. As shown, this difference is not significant. In fact it is believed that the reaction time with the dual-function pedal can be significantly reduced with increased practice

using it. At the end of the week-long test period, the authors administered a road test to themselves in which all signals were randomly given. Table 5 shows that there is a significant difference between the mean reaction time of experienced subjects and those being exposed to the dual-function pedal for the first time. Although this test was a reduced experiment with a small sample size it lends credence to the statement that with practice and familiarity reaction times with the dual purpose pedal can be even faster (an additional 15%) than the results of this experiment indicate.

It is significant to note that nearly all the test subjects adapted quickly to the combined pedal and were enthusiastic about the concept. None of the subjects indicated experiencing any discomfort with the dual function pedal.

In conclusion, the combined brake-accelerator pedal is a viable concept that can significantly reduce brake reaction time under normal operating conditions.

TABLE 5

Student's t-test for Difference Between Mean Reaction Times of Experienced vs. Inexperienced Subjects

Combined Brake Pedal

Experiment	Sample Size	Sample Variance	Sample Mean
Inexperienced	17	0.001537	0.316
Experienced	2	0.036175	0.243

Pooled Variance = 0.003575

$t = 5.14^{*}$

*Significant at = 0.01

VII. RECOMMENDATIONS

This experiment has shown that the dual-function pedal can physically brake a moving automobile and while doing so, it can be applied faster than the conventional system. It appears additionally significant that all of the test subjects had many years driving experience during which time the normal braking response was well grooved, yet each was able to consistently achieve faster reaction times with the dual-function pedal on the occasion of their first exposure to its use. It seems reasonable to expect even better reaction times when use of a dual-function pedal becomes equally automatic through experience.

The experiences in designing and trouble-shooting the application of pressure to the master cylinder through the dual-function pedal led to one design recommendation. Downward pressure on the heel of the pedal is transferred through two gears to horizontal force on the lower linkage arm. The gears used tend to bind and require extra initial force to overcome their stationarity. It is recommended that gears be eliminated from the system and their function be replaced by a hydraulic system or a solid, one-piece linkage from pedal to master cylinder. With such a modification even faster reaction times and improved braking action are predicted.

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13. ABSTRACT

This experiment was conducted to compare road test reaction times obtained from a dual-function pedal that was completely integrated into an automobile's accelerating and braking systems.

The resultant mean reaction times, measured from seventeen subjects in tests at Laguna Seca Raceway, Monterey, California, were 0.316 seconds for the dual-function pedal and 0.450 seconds for the conventional brake pedal. Analysis of variance showed that the reaction time when using the dual-function pedal was significantly faster than reaction time when using the conventional pedal at the $p = .01$ level. The results of this experiment show that reaction times using the combined brake-accelerator pedal are faster by 29.8% (corresponding to reducing the stopping distance by 12 feet at 60 miles per hour), than those using the conventional system.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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lower linkage travel						
mechanical advantage						
pedal travel						
reaction time						
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